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Characterizing Moisture Regimes for Assessing Fuel Availability in North Carolina Vegetation Communities

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Final Report Joint Fire Science Program

Project Title: Characterizing Moisture Regimes for Assessing Fuel Availability in North Carolina Vegetation Communities

Project ID: 01C-3-3-21

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Field Sites and Cooperators:

Agency	Sampling Location	Vegetation Type	Cooperator:
<i>US Fish and Wildlife Service</i>	Pocosin Lakes NWR Alligator River NWR Carolina Sand Hills NWR Great Dismal Swamp NWR	Pocosin Pocosin Longleaf Pine/ Pocosin Pocosin	Vince Carver Tom Crews Mike Housh, Mark Parker Tim Craig
<i>Department of Defense</i>	Camp LeJeune Fort Bragg Dare County Bombing Range, Seymour Johnson AFB	Pocosin/ Longleaf Pine LongLeaf Pocosin	Danny Becker, Steve Shepard John Ward Scott Smith
<i>The Nature Conservancy</i>	Green Swamp Preserve	Pocosin/ Longleaf Pine	Margit Bucher
<i>North Carolina State University</i>	Hofmann State Forest	Pocosin	Joe Jarman, Glenn Catts
<i>USDA Forest Service</i>	Croatan National Forest Pisgah National Forest Appalachian Ranger District Grandfather Ranger District	Pocosin Laurel / Rhododendron Laurel / Rhododendron Laurel / Rhododendron	James Cherry
<i>North Carolina Department of Forest Resources</i>	Conley Creek	Laurel / Rhododendron	Derrick Arnie David Greathouse
<i>North Carolina Wildlife Commission</i>	Holly Shelter Game Lands	Pocosin	
<i>National Park Service</i>	Great Smoky Mountain National Park	Laurel / Rhododendron	Mark Taylor

Synopsis

In the southeastern United States prescription burning, fire danger rating and wildfire suppression strategies are constrained by limited knowledge of the influence of moisture content in live vegetation, organic soils, water table and weather. The interactive influence of these factors on fire behavior is not well studied. The 3+ year long study reported here was conducted to gain direct empirical understanding of seasonal fuel and soil moisture dynamics in shrub-dominated pocosin communities, in coastal Virginia and North Carolina, mixed hardwoods communities containing significant laurel and rhododendron understory fuels in western North Carolina and eastern Tennessee, and longleaf pine communities in the Piedmont and coastal plains of North and South Carolina.

From late 2004 through August 2007 live leaf moisture, dead fuel moisture and soil moisture were repeatedly sampled in each of the three regional vegetation communities. The sites were instrumented with data loggers that recorded soil moisture and temperature. Water table depth data loggers were also installed on the pocosin sites.

The results of this complex series of measurements meets the projects goal of filling local and regional knowledge gaps pertaining to soil and vegetation moisture relationships that are directly relevant to fire management plan development and implementation. Four broad areas where our current knowledge limits our ability to predict fire behavior, fire danger and fire effects include: the understanding of the contribution of live fuels to fire behavior in shrub-dominated fuel complexes, the influence of a large proportion of unsound dead fuel on equilibrium moisture content estimation, the moisture limits on consumption of litter, duff and fine fuels in mixed pine/hardwood and longleaf pine wiregrass fuel types, and the influence of hydrology and soil properties on organic soil moisture dynamics and the potential for smoldering combustion in highly organic soils. In this report, following an introduction and discussion of methods, the findings are presented in the following format:

Live Leaf Moisture Measurements

- Pocosin Sites

- Laurel and Rhododendron Sites

- Longleaf Sites

One and Ten Hour Fuel Moisture Measurements

- Pocosin Sites

- Laurel and Rhododendron Sites

- Longleaf Sites

Litter and Duff/Root Mat Moisture Measurements

- Pocosin Sites

- Laurel and Rhododendron Sites

- Longleaf Sites

Digital Data Logger Measurements/Soil Moisture and Water Table

Pocosin Sites

Laurel and Rhododendron Sites

Longleaf Sites

Evapotranspiration, Keetch Byam Drought Index (KBDI) and Fire Danger Rating

Soil Moisture Measurement Comparisons: Hand Sampling, Portable Moisture Probe
and Fixed Position Probe

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Introduction

Fuel Moisture Sample Collection Sites



Figure 1. Fuel moisture sample collection sites.

Southeastern vegetation types with significant live fuel loading and deep organic soils present a serious challenge to fire managers. The management of fuel complexes with these characteristics is currently limited by an inadequate understanding of the role of foliage moisture and organic soil moisture in fire behavior. Live fuels and organic soils are perceived to have narrow thresholds between not burning and sustaining combustion. Although laboratory studies of organic soils have shown this to be the case, our understanding of live fuels is supported largely by observation and anecdotal evidence.

Live fuel moisture content has been sampled in many of the western states. Field sampling programs of live fuel moisture content allow tracking of vegetation moisture status over the growth season and through an area's fire season. Collected live fuel moisture data portrays differences in seasonal trends between years, vegetation types, and specific locations. Combined with local fire occurrence and fire behavior knowledge, these trends give some sense of fire potential and of critical fuel moisture values.

Previous studies of southeastern live fuels have documented local moisture trends in several species. However, in comparison with western species, the live fuels of the southeastern region have received less attention. Reifsnyder (1961) studied mountain

laurel and soil moisture content and reported no clear relationships between drought and leaf moisture content. Blackmarr and Flanner (1975) documented live fuel moisture trends in a variety of species of pocosin shrubs. They stated that further insight could be gained by studying moisture variation during critical spring and fall periods. Wendel and Story (1962) measured moisture content in pocosin species for one year and showed that the periods of lowest vegetation moisture content coincided with the periods of greatest fire occurrence in North Carolina.

In North Carolina, persistent evergreen shrub communities are commonly associated with organic soils on the coastal plain and the understory shrub layers of forest communities in the mountain areas. Examples of these fuel types are coastal plain pocosin communities that are dominated by gallberry (*Ilex glabra*) and fetterbush (*Lyonia lucida*) and plant communities in mountainous areas with dominant mountain laurel (*Kalmia latifolia* L.) and rhododendron (*Rhododendron* sp.) shrub components. Both plant communities are characterized by large amounts of live fuels and potentially extreme fire behavior.

This study was conducted over a longer period of time and wider geographic range than previous studies. Long term fuel moisture measurements can provide a useful starting point for estimating intermediate-scale fuel moistures in computer simulations that now use only a broad-brush fuel moisture assignment across the simulation area. Ultimately, this refined understanding of the interdependent nature of foliage and soil moisture dynamics will lead to improvements in predictions of fire danger rating, fire effects and fire behavior.

Methods

Sample sites representative of the live fuel complexes of concern and were selected within Atlantic Coastal Plain, Piedmont and mountain regions that span North Carolina's geographic extent. Pocosin communities were sampled within Atlantic Coastal Plain from The Great Dismal Swamp in Virginia at the northern extent of the study area to the Green Swamp at the southern extent. Forest communities with a mountain laurel shrub component and rhododendron communities were sampled in the Great Smoky Mountain National Park and the National Forests of North Carolina in the Appalachian Mountains of eastern Tennessee and western North Carolina. longleaf pine (*Pinus palustris*) - savannah communities were also sampled within the Piedmont and coastal plain locations due to its importance to managers. Sampling of longleaf pine communities was conducted at the Carolina Sand Hills NWR, Fort Bragg, Camp LeJuene, and the Green Swamp (Figure 1). The sampling sites were frequently prescribe burned and the surface vegetation was dominated by wire grass and turkey oak.

Sampling began in the fall of 2004 when sites were selected and instrumented with automated digital data logging equipment. Sampling of leaf moisture continued through August of 2007. Due to the lack of significant precipitation in 2007 and 2008 and high

fire activity on the coastal plain, data logging of the pocosin sites has continued through the summer of 2008. A total of thirty sites were sampled at 15 locations during the 3+ year study period.

Sampling at each site was scheduled at two week intervals. However actual sampling was dependent on rainfall and site accessibility and winter sampling was conducted on the mountain sites when conditions permitted. At each site, live leaf moisture content of the dominant evergreen (ericaceous) species was measured. One to three species were selected per site and represented the dominant species of concern to fire managers. Samples of each species included new and mature leaves and each sample was composed of material from multiple plants. Three composite samples of each species were collected per visit.

Dead fuel moisture content was determined for 0 to ¼ inch diameter and ¼ to 1 inch diameter dead woody fuels. One and ten hour dead fuels were collected from the litter surface. On the pocosin sites aerial dead fuels were collected from within the shrub canopy from October 2006 through August 2007.

Litter, duff and soil moistures were sampled on the mountain laurel and rhododendron sites while litter, root mat, and organic muck soil moistures were sampled on the coastal plain pocosin sites. Because there are currently no on-site automated methods for the measurement of duff or root mat soil moisture, moisture in the soil horizon was measured destructively. Three samples of each component were collected at each visit and moisture content was determined after oven-drying at 90⁰c for a minimum of 24 hours. Moisture content is expressed on a dry-weight basis. In addition, the moisture content of mineral soil and the sapric organic soil horizons were also estimated with automated data logging equipment

Each study site was equipped with a data logger that recorded hourly soil moisture. Muck soil and mineral soil measurements were conducted with soil moisture probes (CS 615 Campbell Scientific, Logan Utah) and recorded at hourly intervals on a data logger (SGT Engineering, Champaign, Illinois). Soil moisture probes were placed at the duff and root mat/soil interface. One probe inserted vertically measured average moisture content along its 30 cm length while the 2nd probe which was inserted at a 45⁰ angle measured the average moisture at 15 cm depths. The soil moisture probes were calibrated to muck organic soil and mineral soil gravimetric moisture content.

Because ground water levels have historically been used as an indicator of ground fire potential in the pocosin vegetation type, automated ground water level measurements were made on these sites using ECOTONE ground water wells (Remote Data Systems, Whiteville, North Carolina).

Soil textures, percent sand silt and clay and water retention characteristics were determined for three samples of mineral soils from each mountain and longleaf pine sites. Permanent wilting points are reported in relation to dry mass weights.

Results

• Live Leaf Moisture Measurements

Foliage moisture contents showed a wide range in variability (Figure 2). The lowest average moisture contents which occurred in turkey oak and wiregrass on the longleaf pine sites were less than 5% and 11% while moisture contents over 200% were measured in the new foliage of the species on all sites.

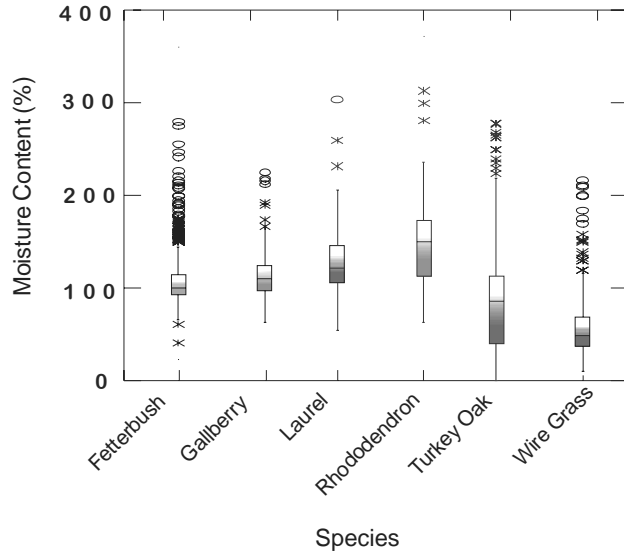


Figure 2. Box plots of the moisture contents of sampled species from January 2005 thru August 2007

• Pocosin Sites

The moisture contents of the two dominant pocosin species were lowest in mid to late winter (Figure 3), but the mean leaf moisture contents of most sites remained above 60% during early spring fire season. Both species showed an increase in foliar moisture that was associated with new growth which occurred during mid to late spring fire season. Foliar moisture then declined slowly during the summer as the new growth aged. Bridgham (1991) reported litter fall throughout the year and increases in the litter accumulation rate of tall and short pocosins occurred in November. However, the results of this study show no clear relationship between peak leaf fall and leaf moisture when measured at 2 week intervals.

The results of spring prescribed burning of similar sites in North Carolina with a 99.6% average vegetation moisture content (foliage, live woody and needle drape) resulted in an average vegetation consumption of 73% (Taylor and Wendel, 1964). The results of fall prescribed burning of pocosin sites conducted in the Green Swamp preserve in 1997 and 2001 showed significant live fuel consumption with an average foliar moisture content of 110%. A similar burn with an average foliar moisture content of 207 % conducted during wetter conditions in 2001 showed no live fuel consumption (Hungerford and Reardon, unpublished data).

A simple analysis of fire behavior and pocosin foliage moistures was conducted using the Rothermel fire spread rate model. The model results suggest that during late spring and early summer the expected foliar moistures would have only a limited dampening effect on fire spread and the model spread rate was more sensitive to wind speed. Current limitations of modeling moisture damping of fire spread in mixtures of live and dead fuels have been discussed by Wilson (1990) and Catchpole and Catchpole (1991).

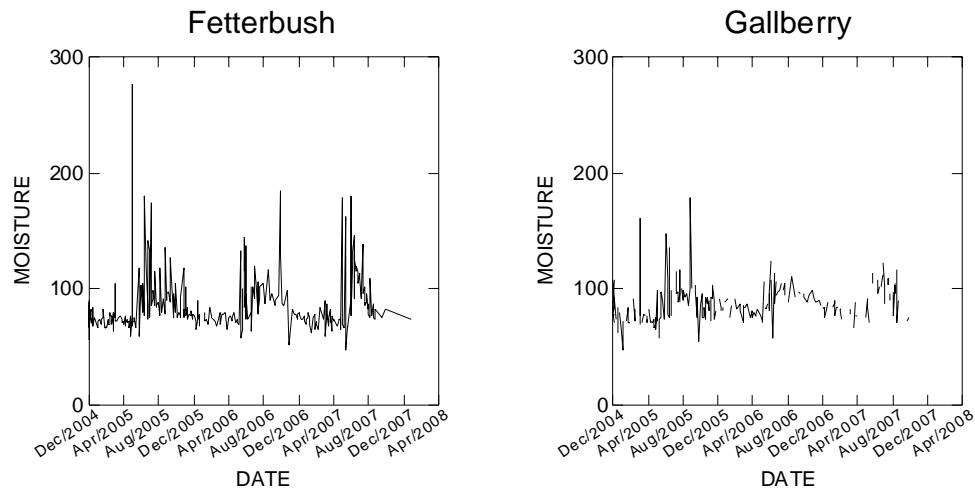


Figure 3. Moisture contents of two dominant shrub species on pocosin sites

- **Laurel and Rhododendron Sites**

On the mountain sites the moisture contents of laurel and rhododendron were lowest in winter to early spring and increased in late April and May (Figure 4). The increase in moisture coincides with middle to late spring fire season in North Carolina. Monk et al (1985) reported distinct patterns in leaf fall of the two species. Laurel dropped its leaves throughout the year with two peak periods in spring and fall while leaf fall in rhododendron was mostly during the fall. The results show no clear patterns in the relationship between leaf fall and leaf moisture when measured at 2 week intervals.

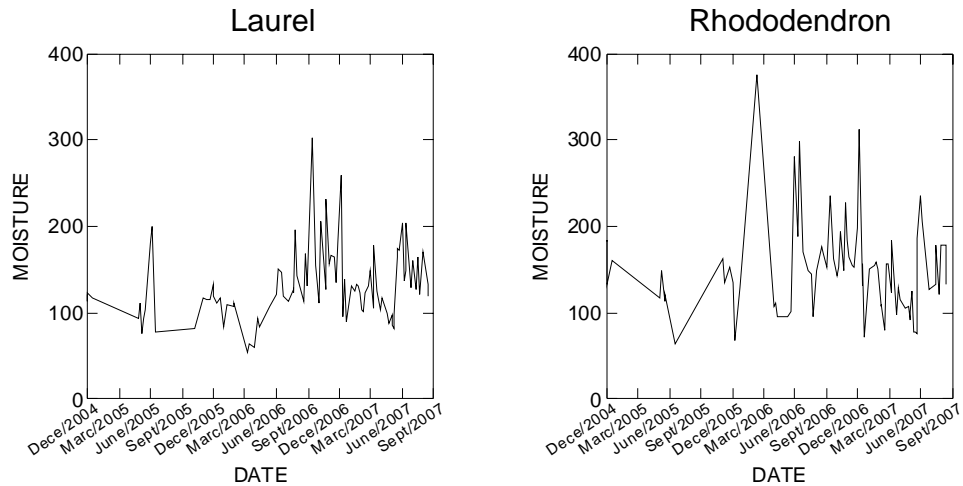


Figure 4. Moisture contents of dominant shrub understory species on forested mountain sites. Note: the coarse moisture trends during 2005 are attributable to an irregular sampling schedule during that time.

- **Longleaf Pine Sites**

During this study the widest range of foliage moistures and lowest moisture contents were observed on the longleaf pine sites. Turkey oak foliage rapidly increased in moisture in late April and early May with the growth of new leaves (Figure 5). Although wire grass did increase in late spring, the peak moisture content of this species was in mid-summer. The results show increases in foliar moisture content of both species during spring fire season in North Carolina.

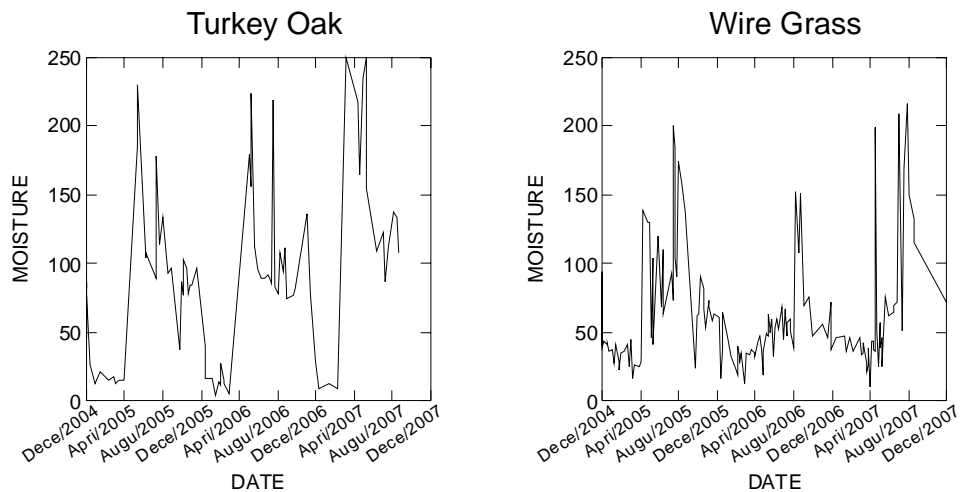


Figure 5. Moisture contents of two dominant understory species on longleaf pine sites

- **One and ten hour dead fuel moisture measurements**

Measured one hour and ten hour moisture contents were lowest on the longleaf sites where they ranged from 6 to 76% and 6 to 134% respectively. Moisture contents were highest on the pocosin sites where they ranged from 3 to 158% and 6 to 161% respectively (Figure 6). The mean site moisture contents within each fuel type were similar but there were differences in the moisture content distributions. The fuels on the pocosin sites showed the widest range in moisture content variability.

When compared with a fiber saturation point of 35% that is commonly associated with sound dead woody fuel our results show the upper moisture content range on all sites was higher than expected. The higher moisture contents may reflect a greater proportion of unsound fuels resulting from the higher decomposition rates normally associated with eastern plant communities.

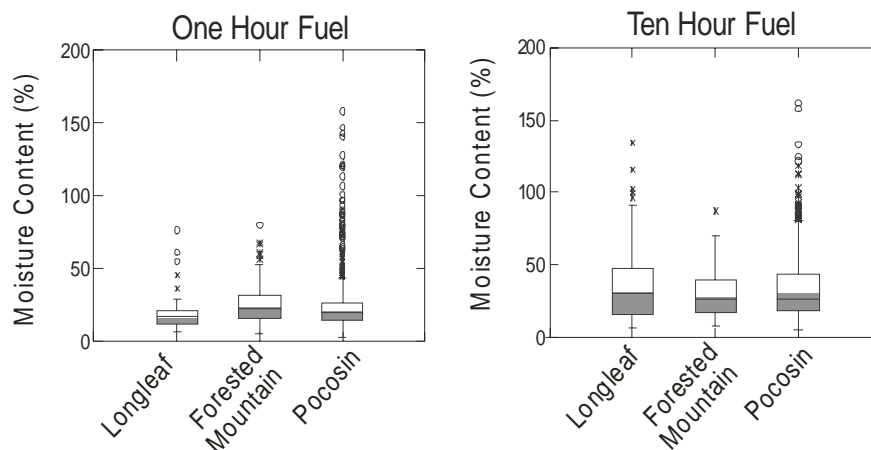


Figure 6. Box plots of litter and dead fuel moisture from January 2005 through August 2007.

- **Pocosin Sites**

The results show that mean one-hour fuel moistures on the pocosin sites were consistently below 15 % from late spring through the summer in 2006 and 2007 (Figure 7). During that time, ten hour fuel moistures were between 10 and 20%. These fuel moistures were in agreement with low root mat and soil moistures in the pocosins during that time. As discussed previously the pocosin fine dead fuels show a greater range of moisture contents in the one and ten hour fuel classes than would normally be expected from sound wood.

The moisture content of the aerial dead fuels was lower than the surface dead fuels and more consistent with the expected value of sound wood. Aerial dead fuel moistures range from 8 to 49% with 75% of the moisture distribution was between 8 and 33%.

Aerial fuel moistures were consistently below 20% throughout much of January to August in 2007.

Fall prescribed burns of pocosin communities were conducted with contrasting moisture conditions in the Green Swamp preserve in 1997 and 2001. The results of prescribed burning with an average ten hour moisture content of 14% showed significant fine fuel consumption. In contrast, a later burn with an average ten hour moisture content of 39.7% conducted under wetter conditions showed very limited consumption of ten hour fuels (Hungerford and Reardon, unpublished data).

The fine fuel moisture content dynamics of this study are consistent with the results of our previous prescribed burning. The low moisture contents of pocosin fine fuels measured during the late spring through the summer agree with observations that fires occurring from late spring through summer commonly result in significant fine fuel consumption.

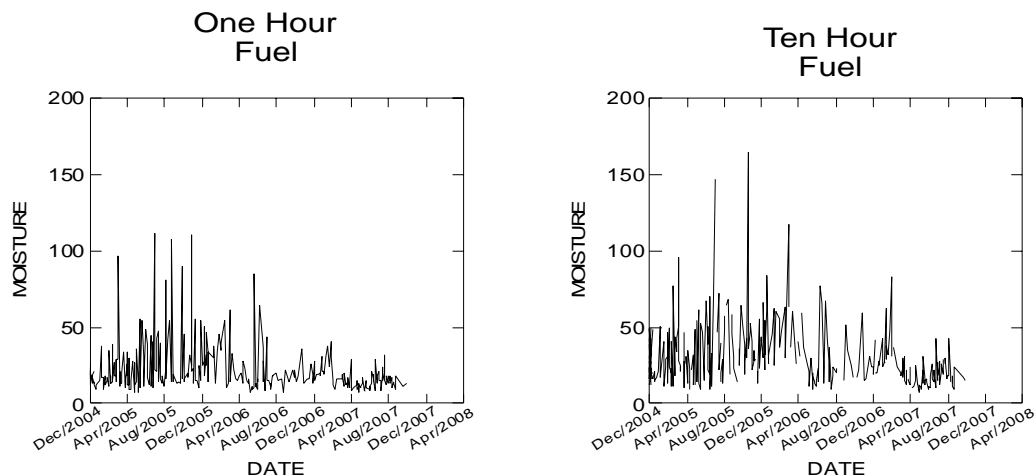


Figure 7 Moisture content of the fine dead fuels on the Pocosin sites.

- **Laurel and Rhododendron Sites**

The results show similar seasonal patterns in the one and ten hour fuels on the mountain sites. In 2006 and 2007 the moisture contents of the one and ten hour fuels were below 10% and 15% intermittently from the late spring through the summer (Figure 8). The results show the moisture content range was generally lower in the ten hour fuels than the one hour fuels.

The results of prescribed burning in stands in southwestern North Carolina that were characterized by a mixed pine/hardwood overstory and a dense laurel understory showed 100% consumption of one hour fuels at moisture contents of 16 to 28% and 84 to 98% consumption at moisture contents of 23 to 38% (Swift et al. 1993)

The results of this study are consistent with the results of the previous work by Swift et al (1993). The moisture contents were at levels that would support consumption during the spring and summer months of 2006 and 2007.

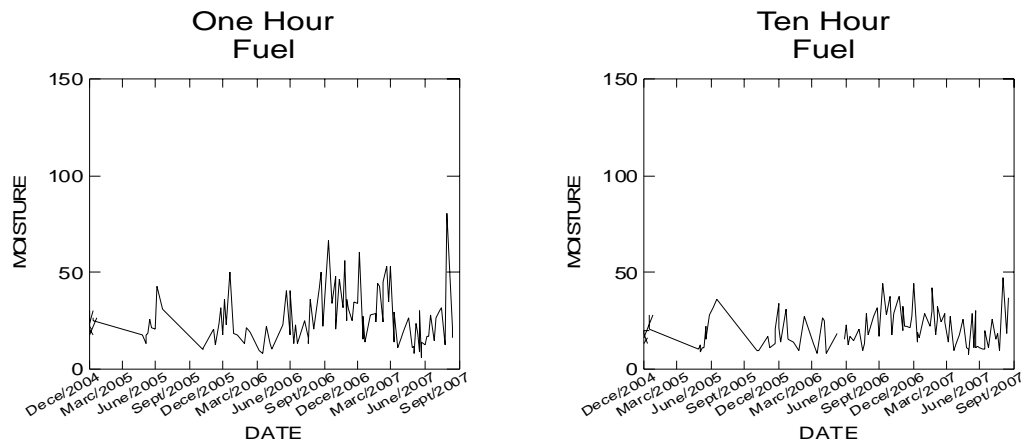


Figure 8. Moisture contents of surface fuels on the forested mountain sites. Note: the coarse moisture trends during 2005 are attributable to an irregular sampling schedule.

• Longleaf Pine Sites

One and ten hour fuel moistures contents were intermittently between 10 and 20% during late spring in 2005 and frequently in this range during late spring and summer in 2006 and 2007 (Figure 9). One and ten hour moisture contents greater than 50% and 75% were frequent during the winter months of 2005, 2006 and 2007.

The prescription guidelines commonly used in the planning and implementation of prescribed burns in longleaf pine and other cover types are based on standardized fuel sticks or ten hour moisture contents predicted by National Forest Danger Rating System (NFDRS). As discussed previously the results of this study show a greater range of moisture contents in the one and ten hour fuel classes than would normally be expected from sound wood.

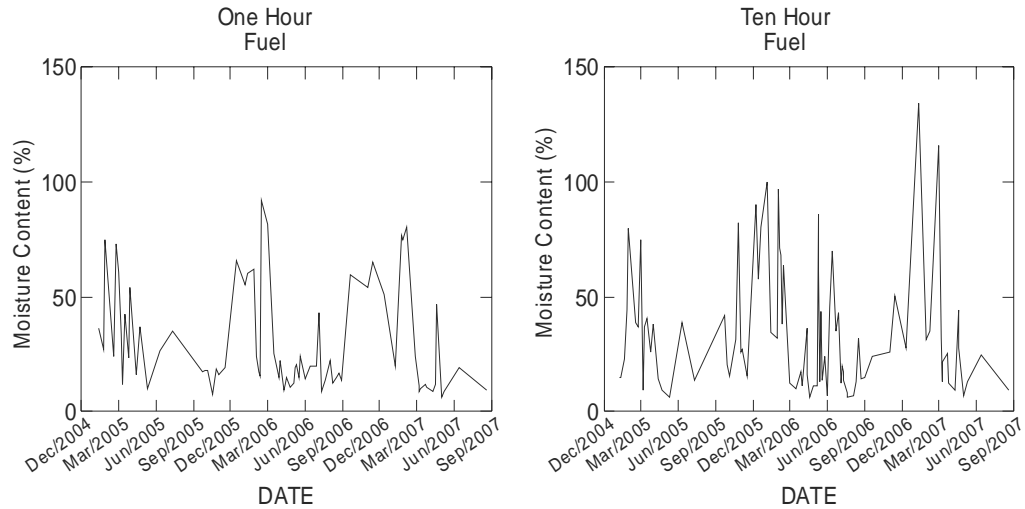


Figure 9. Moisture contents of fine dead fuels on longleaf pine sites

• Litter and Duff / Root Mat Moisture Measurements

The conifer-dominated litter moisture of the longleaf sites was consistently lower than the evergreen/hardwood-dominated litter moisture on the pocosin and mountain sites. (Figure 10, left).

The duff moisture contents on the mountain site were lower and showed less variability than the root mat of the pocosin sites (Figure 10, right). The results suggest that duff/root mat moisture content differences reflect the frequent flooding of the pocosin communities and soil property differences. The longleaf pine sample sites selected were burned frequently and there was no appreciable duff accumulation.

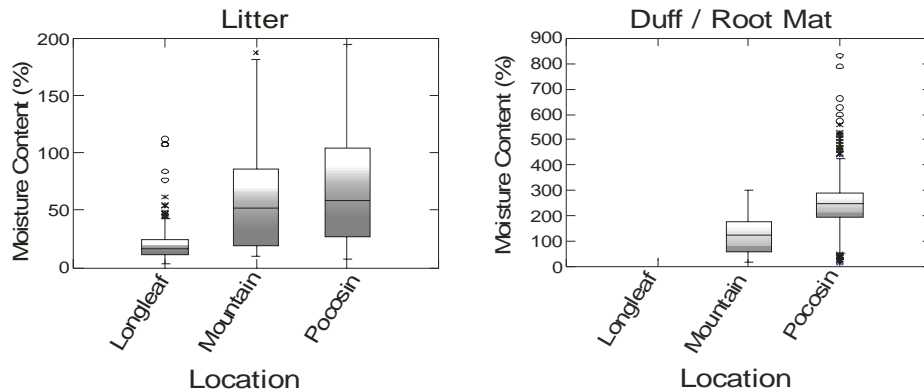


Figure 10. Box plots of duff/root mat moisture content distribution from January 2005 thru August 2007.

- **Pocosin Sites**

Moisture contents of the litter and root mat fuels on the pocosin sites varied from 7 to 191% and 14 to over 800% respectively. The moisture content of these fuels was lowest from early April to September during this study (Figure 11).

The results of spring prescribed burning of pocosin sites in North Carolina showed an average litter consumption of 19% when the average litter moisture content was 124% (Taylor and Wendel 1964). The results of fall prescribed burning of pocosin sites under dry conditions in the Green Swamp preserve showed significant consumption of litter and root mat soils with moisture contents of 21% and 99.5% respectively. Prescribed burning under wetter conditions with moisture contents of the litter and upper root mat soils at 114% and 116% respectively resulted in very limited consumption of the litter and no significant root mat consumption (Hungerford and Reardon, unpublished data).

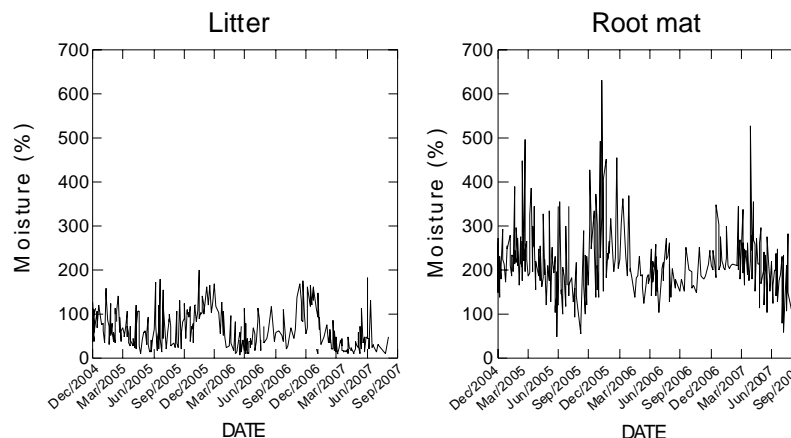


Figure 11. Moisture contents of root mat on Pocosin Sites

- **Laurel and Rhododendron Sites**

The results of litter moisture measurements on the forested mountain sites show low moisture contents during the spring and summer months in 2006 and 2007 when litter moistures were intermittently below 20% (Figure 12). Trends in duff moisture were less consistent than trends in litter moisture. Duff moistures were intermittently below 50 % in the early spring through summer in 2006. The duff moisture was more consistent in the early spring through summer in 2007 when duff moistures were consistently below 50% during that period (Figure 12).

The results of prescribed burning in mixed pine and hardwood stands with a dense laurel understory in south western North Carolina showed that duff reductions of 67 to 30% were reported at moisture contents of 59 to 99% (Swift et al 1993).

Laboratory studies of the smoldering combustion moisture limits have been conducted on a wide range of organic soil materials (Frandsen 1986, Hungerford 1995). The results of those laboratory studies applied to the duff soil horizons from the mountain sites suggest that duff from these sites with an average mineral content of 4% is expected to support sustained smoldering greater than 50 % of the time at moisture contents of less than 104.6%.

Based on the duff moisture measurements made during this study and the previous studies conducted by Frandsen (1996) and Swift (1993), duff moisture was consistently at or below the levels predicted to support smoldering throughout much of this study. However, these predictions are not consistent with observed fire occurrence in North Carolina and demonstrate the need for improved understanding of the limits of duff consumption in the mixed pine/hardwood fuel types.

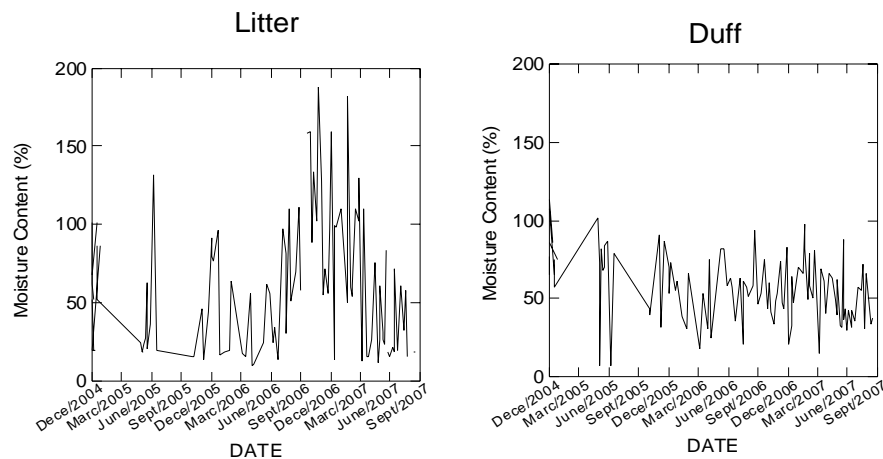


Figure 12. Mean litter and duff moisture content on the mountain sites

- **Longleaf Pine Sites**

The high variability of the litter moisture on the longleaf pine sites reflects the immediate influences of short term changes in precipitation, relative humidity and other factors. Litter moistures ranged from 4 to 112% and moisture contents were below 15% consistently during late spring and summer in 2005, 2006 and 2007. Duff moisture was not sampled on the longleaf pine sample sites because these sites have been burned frequently so there was no appreciable duff accumulation (Figure 13).

Estimates of litter layer consumption were developed from prescribed burning of slash/longleaf, gallberry/palmetto coastal plain sites (Hough 1968). The results of that study reported litter layer consumption as a function of moisture content and litter layer fuel loading. Litter layer consumption of 50% was expected from backfires conducted when litter moisture contents ranged from 40% to less than 140% and loadings were

between 0.2 to 1.0 lbs/ft². An increase in consumption to 80% was expected when litter moisture contents were less than 40% and loading was less than 0.3 lbs/ft².

Litter fuel loading on the longleaf sample sites was low and the results of the previous study by Hough (1968) suggest a consistently high likelihood of significant litter consumption throughout the year. Later work by Hough (1978) was expanded to include available litter and understory fuel loadings and other factors as multivariate predictors of fuel consumption. A comparison of the results of this study with this previous work is not consistent with observed fire occurrence patterns in North Carolina and suggests a need to improve our estimation of litter/ duff consumption in coastal plain longleaf sites dominated by wiregrass/ turkey oak surface fuel.

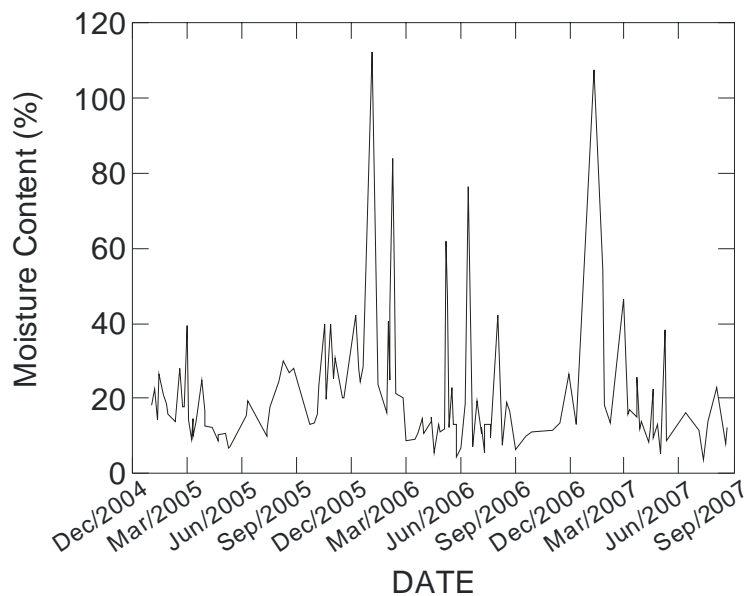


Figure 13. Mean litter moisture on the longleaf pine sites.

- **Data logger measurements / Soil Moisture and Water table**

- **Pocosin Sites**

The reported wilting point (water held at 15 bars) of the disturbed organic soils similar to soils present on the pocosin sites in Dare County and Pocosin Lakes NWR was 48.6% (Lilly 1981). Soil moistures ranged from above 180% to saturation levels of 450%. Soil moisture contents remained substantially above the wilting point throughout the study (Figure 14).

Muck soils showed consistent seasonal trends and soil moisture changes were consistent with leaf moisture changes. The average muck soil moisture content was highest during early fire season in March and decreased beginning in late May and June and thru summer while in late spring leaf moistures were highest as a result of new growth and decreased throughout the summer as the new growth matured.

Previous work by Reardon et al (2007) established moisture limits on sustained smoldering in root mat and muck soils in North Carolina. The estimated probability of sustained smoldering after ignition in muck soils with moisture contents of 250% and 300% is 14 % and 2% respectively. The average muck soil moistures from four study sites show low estimated smoldering potential during the summer months of 2005 and 2006 when soil moistures were greater than 250% but the estimated smoldering potential in August 2007 was greater than 40% when the average soil moisture was below 210 %. However there were site differences in soil moisture and water table response during the study period.

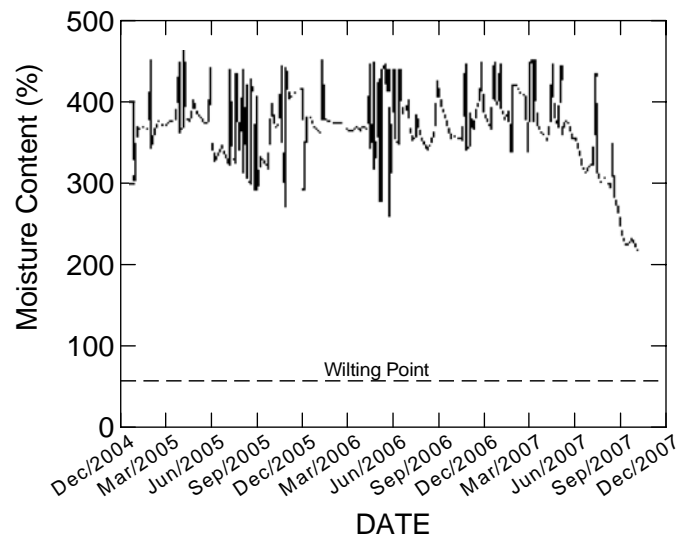


Figure 14. Box plots of duff/ root mat moisture content distribution from January 2005 thru August 2007.

Between 2005 and 2007, the range of maximum water table depths across the study sites varied from 34.0 cm to lower than 110.0 cm. The maximum depth was lower than 110 cm on the Hofmann Forest Wide Open Road site in 2005 and in 2007. In contrast, maximum water table depths were consistently closer to the soil surface on the DCBR Lake Worth Road and Long Curve Road sites.

Although the general patterns of water table depth and soil moisture response to yearly and seasonal precipitation differences were similar, the relationship between maximum water table depths and minimum soil moisture was not consistent. In 2007 the maximum water table depths on the Croatan NF site and Long Curve Road site were 74 and 70 cm below the ground surface respectively. Soil moistures of the 15 cm depths decreased on the Croatan NF site from near saturation levels in January to 330% in October with low smoldering potential at that time. The soil moistures on the Long Curve site decreased to 164 % from near saturation in January to a greater than 50% potential of sustained smoldering. A similar response was present in comparison of the 2005 Lake Worth and Pocosin Lakes site where the water table of the Pocosin Lakes

site was 30 cm deeper than the Lake Worth site but 15 cm soil moisture contents on that site were 32% higher.

- **Laurel and Rhododendron Sites**

The results of the soil textural classification of the mountain sites ranged from sandy loam to sandy clay loam on the laurel dominated sites and ranged from sandy loam to loam soils on the rhododendron dominated sites. The average wilting point of these soils (water held at 15 bars) was 10%. Soil moistures were substantially higher than the wilting point throughout this study.

The mountain sites showed a highly seasonal soil moisture pattern. During the early spring fire season the soils were saturated. Leaf moistures of the laurel and rhododendron species increased from spring through early summer when soil moistures were stable to declining (Figure 15). The soil moistures of the Grandfather Mountain upper laurel site exceeded 40% early in 2007 and declined to 19% by early summer. During that same time period laurel and rhododendron leaf moistures increased.

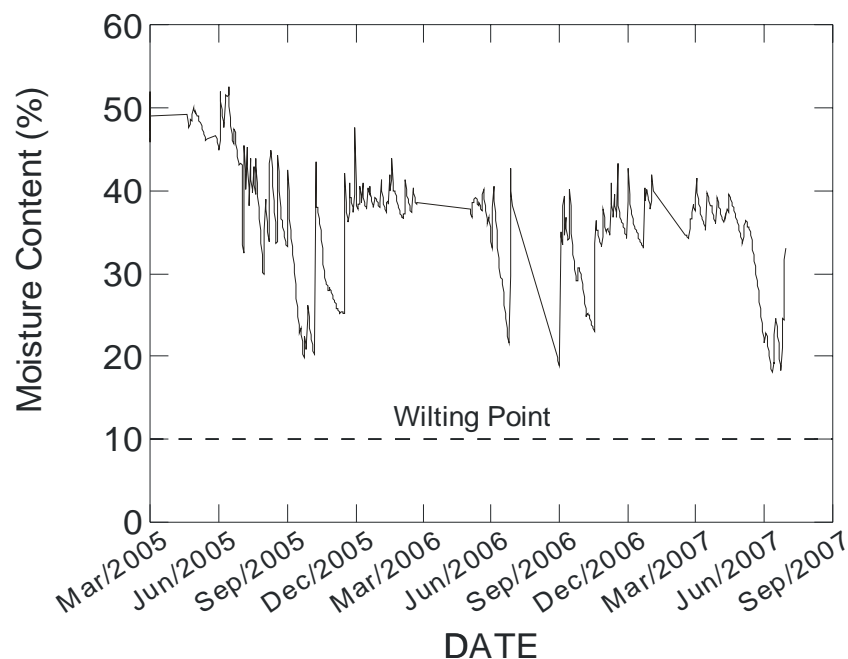


Figure 15. Average mineral soil moisture content (0-5 cm depth) from the upper laurel sampling site at Grandfather Mountain. from June 2006 thru August 2007

- **Longleaf Pine Sites**

The results of soil textural classification of the longleaf pine sites ranged from sand to loamy sand soils. The average permanent wilting point of these soils (water held at 15

bars) was 4.5 %. Soil moisture dynamics shown for the Fort Bragg sampling site are representative of moisture content trends on the other sampling sites (Figure 16). Moisture contents on these sites were lowest in late spring.

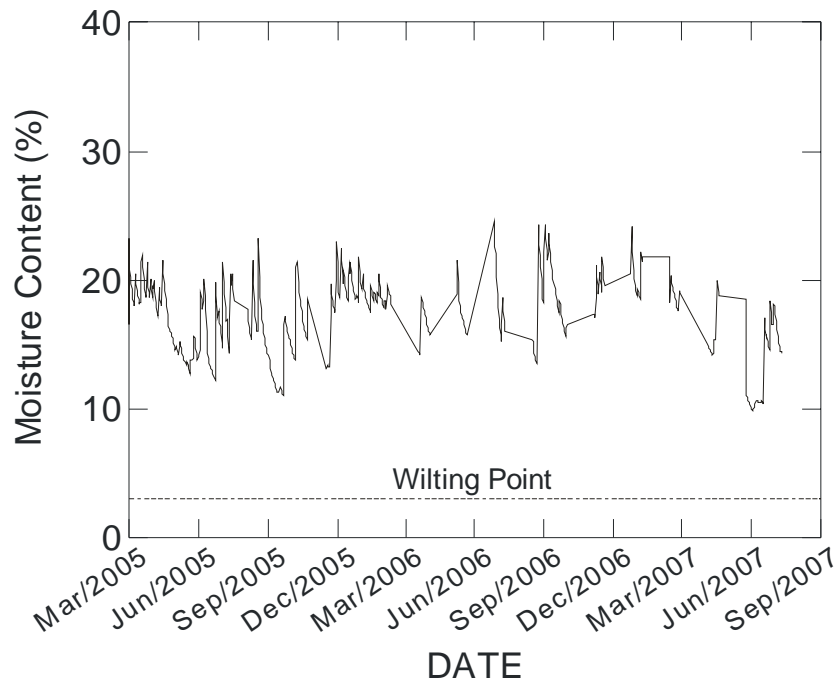


Figure 16. Average soil moisture content (0-6 cm depth) from the Fort Bragg longleaf pine sample site from January 2005 through August 2007.

- **Evapotranspiration, Keetch Byram Drought Index (KBDI) and fire danger rating**

Owing to a number of assumptions fundamental to the KBDI that were questionable when applied to organic soils, we originally proposed that evapotranspiration might be a more accurate indicator of fire danger in pocosin wetland soils. The data show a close link between the KBDI and local estimates of evapotranspiration (Figure 17). Our results suggest that while the annual water budgets of pocosin wetlands are dominated by evapotranspiration and precipitation, there are other significant inputs or factors influencing the distribution of soil moisture in pocosin systems.

The results show that the KBDI was not a reliable predictor of ground fire potential. The index frequently over estimated smoldering potential in root mat and muck soil but did not under estimate smoldering potential during this study. Because the index is a

function of meteorological inputs the sensitivity of the KBDI to local soil, plant community and hydrologic influences is limited. The findings of this study suggest that improvements in fire danger prediction in pocosin or other wetland communities can result from the integration of these factors with meteorologically based indices, such as the KBDI (Reardon et al., in press).

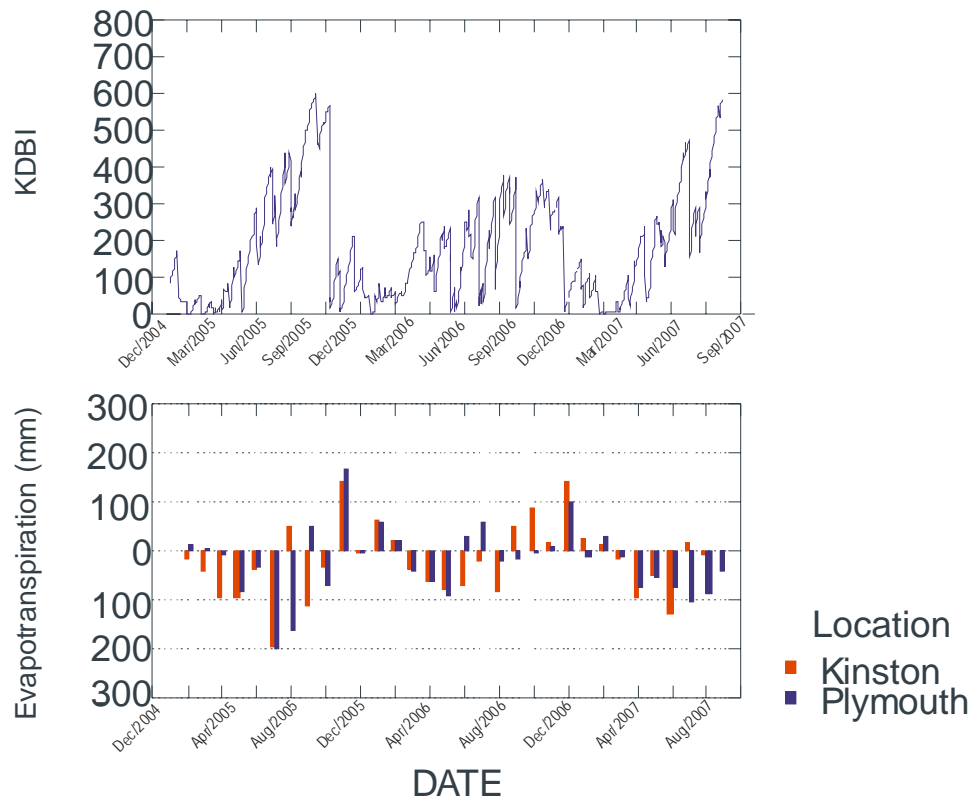


Figure 17. Comparison of the Keetch Byram Drought Index (top) for the Hofmann Forest and local estimates of evapotranspiration at Kinston and Plymouth North Carolina (Bottom).

- **Soil moisture measurement comparisons: hand sampling, portable moisture probe and fixed position probe**

Soil moisture contents of the mountain, longleaf pine and pocosin study areas that were determined by hand sampling showed higher variability than the soil moisture contents determined by fixed moisture probe sampling. Hand moisture measurements of the organic soils associated with wetland sites (Figure 18), support the findings of Munro (1982) who reported that disturbance during hand sampling of wetland soils resulted in the overestimation of soil moisture.

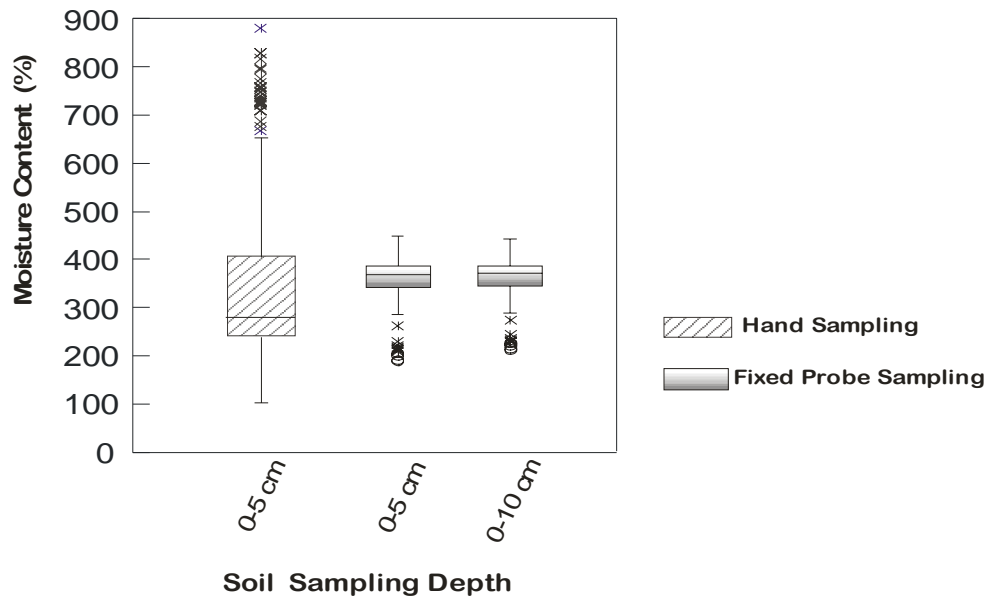


Figure 18. Comparison of soil moisture content distributions from hand sampling and fixed soil moisture probes

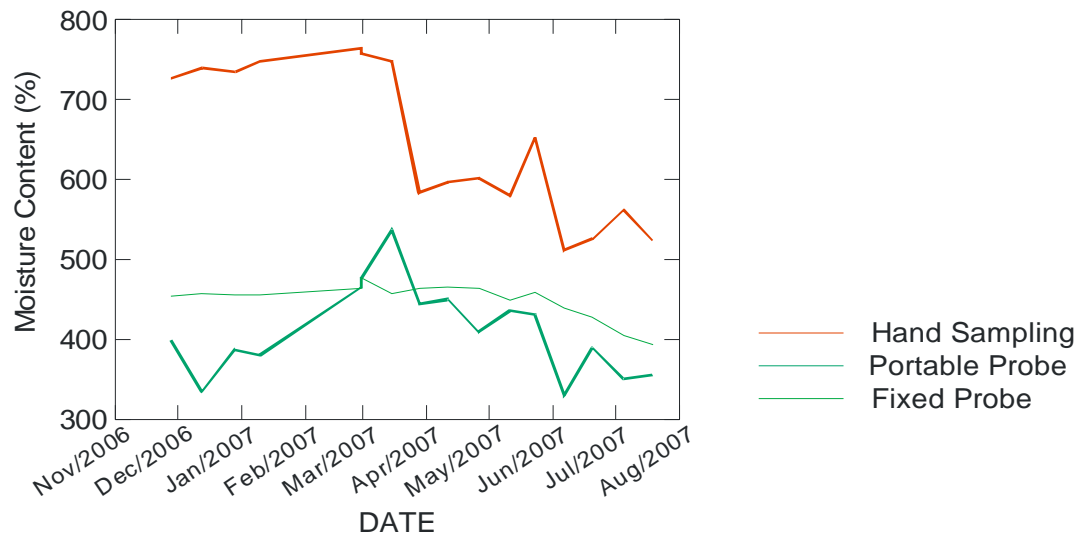


Figure 19. Comparison of soil moisture estimations from hand sampling and the use of fixed and handheld moisture probes

Some variation in the moisture contents that were determined by fixed and portable probe sampling may be attributable to spatial variability and the variability in the depth of sampling. We conclude that for these sites sampling of the sapric (muck) organic soil horizons with a probe type sensor is more consistent than hand sampling. Additional

research and development could lead to an instrument with broad applicability and suitable for use by field crews.

- **Root mat moisture sensor**

Because the soil moisture probes used in this study require consistent surface contact along the probe length, they were not suitable for use in the root mat soils with their highly porous and heterogeneous structure. This probe is typical of most commercially available products. At this time we are unaware of any commercial product suitable for reliable real time moisture measurements in these substrates. To fill this need, a surface wetness sensor was modified to measure drying within the root mat hummock structure. The results show that root mat moisture drying trends were poorly correlated with moisture contents of hand sampling conducted at two week intervals. However the drying trend in Figure 20 suggests that the drying of root mat soils is linked with the seasonal factors, the period between rainfall events and the amount of precipitation. The results are inconclusive and support the need for additional research and development in this area.

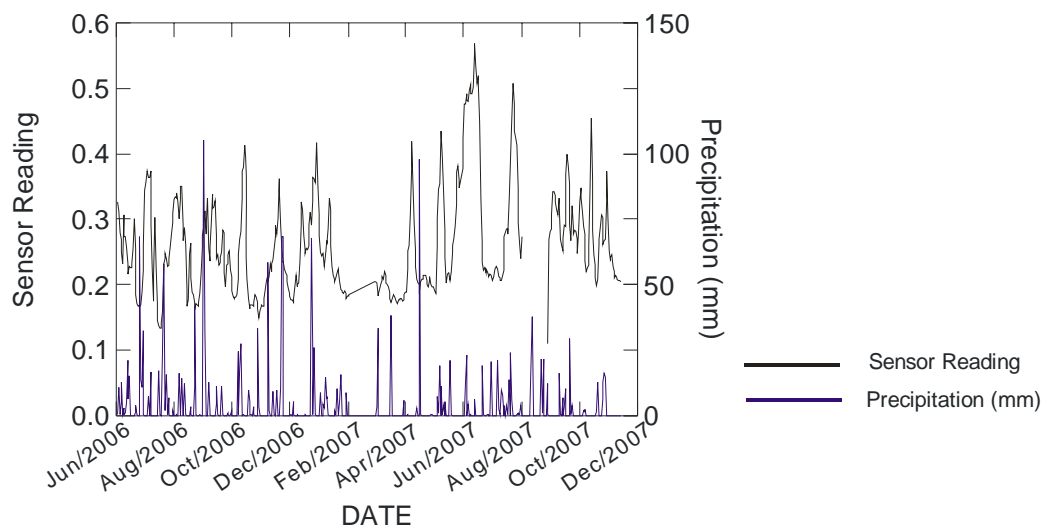


Figure 20. Comparison of readings from prototype moisture sensor placed in root mat soils and precipitation patterns

Summary

Foliar moisture contents showed distinct annual patterns with the highest moisture contents linked to spring growth during mid to late spring fire season. During this study, the foliar moisture increases occurred in conjunction with decreases in fine fuel and soil moisture during that time. Because significant fires commonly occur in pocosin and forested laurel communities during late spring to early summer, the results suggest

that foliar moisture is not the sole factor determining fire spread in these communities. Factors influencing fire spread and intensity in non-homogeneous fuels, which are exemplified by shrub dominated fuel complexes, have been identified in several studies. Catchpole and Catchpole (1991) modeled moisture damping of fire spread rate as a function of moisture content and particle surface-area to volume ratio. Schwilk (2003) discussed the influence of dead branch retention and canopy architecture in chamise evergreen shrub communities on fire intensity. Our results and the results of these studies indicate that a better understanding of the relationship between foliage moisture content and fire behavior in shrub dominated fuel complexes is needed for more effective use of foliage moisture content measurements.

The utility of fine fuel measurements would increase with a greater understanding of fuel dynamics in these communities. Graham and McCarthy (2006) studied fuel dynamics in mixed oak forests and concluded that the fire regimes in eastern forests are most likely driven by a balance between productivity and decomposition rather than long term fuel buildup common in western forests. The effects of decomposition processes are reflected in changes in moisture content range, equilibrium moisture content dynamics and other fuel physical properties that influence fire behavior. The significance of these changes may be dependent on the range of fuel physical properties within the fuel complex, the unsound/sound ratio of the total fuel loading and other factors.

The current literature relating to the relationship between moisture content and litter and duff or root mat soil consumption on pocosin, longleaf and mixed hardwood/conifer sites is limited. A comparison of our results with the results from a study of prescribed burning, which was conducted in forested communities with a significant laurel understory by Swift and others (1991), suggests that improved litter and duff consumption models are needed. The litter and duff moisture contents measured on the laurel and rhododendron sites were consistently below moisture contents that produced significant fuel consumption during that study. Although the likely consumption at the measured moisture contents was at levels consistently expected to support consumption, the anticipated consumption trends were not consistent with the seasonal fire occurrence patterns in North Carolina. Fire behavior, fire danger rating, and emission modeling would directly benefit from improved consumption models.

At present, the available tools for predicting the ground fire risk in pocosin wetlands are limited. Shallow water table wells and the water levels in drainage ditches are commonly used by land managers as informal indicators of localized ground fire risk while more regional estimates of ground fire potential are commonly evaluated using the Keetch Byram Drought Index (KBDI). The results of this study show that the KBDI and water table depths were not reliable predictors of ground fire potential. Future improvements in our abilities to predict local ground fire potential may result from the improved moisture sampling technology while improvements of larger scale estimates may result from the integration of hydrology factors and soil properties with existing drought indices or remotely sensed data.

The results of this study illustrate the interrelated dynamics of foliar, dead fuel and soil moisture and call attention to related areas where insufficient local and regional knowledge limits the utility of these measurements.

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- **Deliverable Crosswalk Table.**

	Proposed	Accomplished	Status
Data Collection	Live fuel moisture Soil moisture Dead fuel moisture	Samples were collected and analyzed from 30 sites at 15 locations from late fall of 2004 until August 2007	Completed
	Automated soil moisture and water table measurements	30 sites at 15 locations were instrumented with data loggers and sensors. Data was collected from late 2004 and continues in July 2008	Ongoing- Data collection on Pocosin sites continues through July 2008
	Development of hand held moisture probe for use in organic soils	Handheld Unit was used by the NCDFR sampling crew. The preliminary results were favorable. Additional work in this area is needed.	Completed
	Development of a sensor for the measurement of soil moisture in porous root mat soil.	Sensors were installed in the Pocosin sample sites. Preliminary results were favorable. Additional work in this area is needed.	Completed
Presentations and Papers	Oral Presentation. “Characterizing moisture regimes for assessing fuel availability in Pocosin, Longleaf Pine and Appalachian Shrub Communities”	East Fire 2005 Conference Fairfax, VA May 2005	Completed
	Poster presentation of live fuel moisture research activities	Visit by the Joint Fire Science Board of Governors. Missoula MT September 2006	Completed
	Poster Presentation “Characterizing moisture Dynamics for Assessing Fuel Availability in North Carolina Vegetation Communities	2 nd Fire Behavior and Fuels Conference, Destin FL, March 2007	Completed

	Oral Presentation – “Soil moisture Dynamics and Smoldering Combustion Limits in Organic soils in Pocosin Communities”	East Fire 2007 Conference Fairfax, VA. June 2007	Completed
	Paper: “Soil moisture Dynamics and Smoldering Combustion Limits in Organic soils in Pocosin Communities”	Accepted for publication by International Journal of Wildland Fire, June 2008	Completed
	Proposed Paper: Relationships of leaf moisture, soil moisture and fire danger rating		Winter 2008
	Proposed Paper: NDVI, live leaf moisture and fire danger rating		Spring 2009
Tech Transfer	On site meetings with individual cooperators to discuss sampling procedures and the use of dataloggers and sensors	Spring and Fall 2004 thru 2007	Completed
	Group presentation and discussion of live fuel moisture research results with cooperators	North Carolina Department of Forest Resources, Regional Office, Kinston N.C.	Completed
	Invited oral presentation of planned live fuel moisture and organic soil moisture research	Onslow Bight Fire Partnership Workshop, New Bern, NC October 2005	Completed
	Presentation and discussion of live fuel moisture research results	Resource Managers, N.C. Department of Forest Resources, Morgantown, NC, October 2006	Completed
	Final meeting with cooperators and invited oral presentation of live fuel moisture and organic soil moisture research results	Onslow Bight Fire Partner Workshop Meeting Atlantic Beach, NC November 2007	Completed

Web Site Development	www.Firefuel Moisture.org	Website established. At present the site has a partial data set and limited graphing capabilities.	Continuing development planned
		Planned -Complete data set and improved website capabilities	Fall 2008

